

Choice of Summer Fallow Replacement Crops Impacts Subsequent Winter Wheat

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ABSTRACT

Winter wheat (*Triticum aestivum* L.) is the foundation of dryland cropping systems in the Central Great Plains. The objective of this study was to quantify the effects of four short-season spring-planted crops used to replace summer fallow on the subsequent winter wheat crop. Wheat was seeded into four crop stubbles [spring triticale (*×Triticosecale* Wittmack), dry pea (*Pisum sativum* L.), foxtail millet (*Setaria italica* L. Beauv.), and proso millet (*Panicum miliaceum* L.)] at sites near Akron, CO, and Sidney, NE, in the fall of 2004 and 2005. These summer fallow replacement crops were planted into silt loam soils at three different soil water levels at planting (low, medium, and high). Winter wheat water use was 3.6 cm greater, and grain yield was 662 kg ha⁻¹ greater in the high water treatment compared with the low water treatment averaged across all sites and years. Winter wheat used an average of 4.3 cm more water following early planted summer crops (triticale and dry pea) than after late planted summer crops (foxtail and proso millet), but this increased water use did not consistently translate into increased grain yield as a result of terminal drought at Sidney in 2006. The high water treatment always had a positive net return. The high cost of pea seed (\$3.30 kg⁻¹, USD) strongly reduced profitability. The flexible summer fallow cropping system appears to be most applicable when using short-duration summer annual forage crops such as triticale and foxtail millet.

IN THE CENTRAL GREAT PLAINS, dryland agriculture developed around winter wheat production. A variable climate with unpredictable precipitation and other weather conditions made, and continues to make, dryland farming in the region inherently risky (Dhuyvetter et al., 1996). Summer fallow, the practice of controlling all plant growth during the noncrop season, was quickly adopted in the region to increase the chances for successful establishment and development of winter wheat and to stabilize winter wheat yields (Lyon et al., 1995; Dhuyvetter et al., 1996; Peterson et al., 1996; Farahani et al., 1998). Winter wheat–fallow is the predominant crop rotation in the Central Great Plains.

When summer fallow began, fallow management often involved numerous tillage operations, including the use of inversion tillage, which buried most crop residues. Less than 20% of precipitation received during summer fallow was stored in the soil for the following winter wheat crop with these practices (Greb, 1979). As

noninversion tillage and herbicides replaced inversion tillage, more crop residue was left on the soil surface. Precipitation storage efficiency increased during this period of time, but the efficiency of soil water storage during the fallow period has been stagnant at about 40% since the 1970s (Greb, 1983; Unger, 1984; Tanaka and Aase, 1987; Dao, 1993; Peterson et al., 1996; Nielsen et al., 2005).

McGee et al. (1997) suggested that greater water storage efficiency could be achieved by terminating fallow in the spring and planting a summer crop. The principle behind cropping intensification is replacement of soil evaporation with crop transpiration (Farahani et al., 1998). Intensified systems in the region generally produce two crops in 3 yr or three crops in 4 yr through the addition of summer crops such as corn (*Zea mays* L.), sunflower (*Helianthus annuus* L.), sorghum [*Sorghum bicolor* (L.) Moench], or proso millet.

Intensification of dryland cropping systems has resulted in pronounced increases in biomass and grain production on an annual basis across much of the Central and Southern Great Plains (Peterson et al., 1993, 1996; Norwood, 1994; Jones and Popham, 1997). Peterson and Westfall (2004) found that intensification of cropping systems increased net return to producers in eastern Colorado by 25 to 45% compared with wheat–fallow. Intensified dryland cropping systems have also increased potentially active surface soil organic C and N (Peterson et al., 1998), effectively controlled winter annual grass weeds in winter wheat (Daugovish et al., 1999), and reduced yield loss in wheat resulting from soilborne disease (Krupinsky et al., 2002).

However, cropping intensification that eliminates summer fallow can have negative consequences. Elimination of the summer fallow period in eastern Colorado resulted in a significant reduction of available soil water at wheat planting and subsequent wheat yield (Nielsen et al., 2002). When fallow was replaced with proso millet in a wheat–corn–fallow rotation, available soil water content at wheat planting was decreased by 48% (9.8 cm). Wheat yield in the wheat–corn–millet system averaged 52% (1530 kg ha⁻¹) less than in the wheat–corn–fallow system. Wheat yield has been reported to be strongly correlated with available soil water at wheat planting (Nielsen et al., 1999; Nielsen et al., 2002; Nielsen and Vigil, 2005), with the response ranging from 39.7 to 282.9 kg ha⁻¹ cm⁻¹. The yield response to available soil water increased with increasing precipitation during May and June.

Lyon et al. (2004) studied the impact of replacing summer fallow with various spring-planted crops prior to winter wheat seeding. Oat (*Avena sativa* L.) and pea for forage or proso millet for grain were economically competitive with systems that included summer fallow, despite reducing winter wheat yields by 23% (450 kg ha⁻¹)

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2004–2005 wheat season and for the surface 30 cm during the 2005–2006 season. During both seasons at Akron, and during the 2005–2006 season at Sidney, soil water measurements at 45, 75, and 105 cm were made using a neutron probe (Campbell Pacific 503 DR, Campbell Pacific, Pacheco, CA). Gravimetric soil water samples from the plot area were used to calibrate the neutron probe. Time-domain reflectometry was used at Akron to determine soil water content in the surface 30 cm of soil. Measurement sites were located near the center of each subplot. Amount of plant available water was determined by subtracting field-observed lower limits of plant water extraction at each site from the total water content at each sampling interval. Lower limits for water extraction at Sidney were 0.09, 0.11, 0.08, and 0.06 cm³ cm⁻³ for the 0- to 30-, 30- to 60-, 60- to 90-, and 90- to 120-cm intervals, respectively. These values represent the lowest observed volumetric water contents in winter wheat at Sidney. At Akron, the values were 0.09, 0.12, 0.07, and 0.06 cm³ cm⁻³, respectively, for the same soil depth intervals.

Immediately prior to harvest, the number of reproductive tillers in a meter of row was determined in each plot. Plants from this meter of row were clipped at the soil surface, dried for 3 wk, and weighed. Grain was threshed and weighed. Harvest index was calculated by dividing the grain weight by the total weight of the nonthreshed sample.

Plots were machine harvested for grain yield. The harvested areas at Sidney were 12.1 m² in 2005 and 13.3 m² in 2006. At Akron, the harvested areas were 17.8 m² in 2005 and 15.4 m² in 2006. Moisture and test weight of grain crops were determined using a grain analyzer (GAC-2000, Dickey-John, Auburn, IL). Grain yield was adjusted to 125 g kg⁻¹ water content.

Gross returns for each crop were calculated using 5-yr average prices. Winter wheat and proso millet prices were from local markets. Triticale and foxtail millet hay prices were based on local alfalfa hay prices adjusted to 80% of the alfalfa (*Medicago sativa* L.) price. This adjustment reflects the lack of market reporting in summer annual forages and a perceived lower value for these forages. The nearest market for dry pea is located in eastern North Dakota, so the 5-yr average price for North Dakota was used. Cost of production budgets were developed for each summer annual crop and the winter wheat using the University of Nebraska Budget Generator. Net return, as defined for this project, is a residual return to land and management, without any USDA farm program payments or crop insurance cost or indemnities. Annualized net return is determined by summing the return from the summer annual crop and winter wheat in the following year. This total value is halved to determine the annualized net return.

Data were analyzed with PROC MIXED (SAS Inst., 2001). There were significant site-year × crop and site-year × water treatment interactions for many of the parameters measured, which prevented pooling of data across sites and years. There were no significant crop × water treatment interactions for any of the parameters measured, and therefore, crop treatment means are averaged across all water treatments and water treatment means are averaged across all crop treatments. Treatment means, with the exception of economic net returns, were separated by a priori single degree of freedom orthogonal contrasts. Net return means were separated using Fishers' protected LSD at the 0.05 probability level.

RESULTS AND DISCUSSION

In 2004 at Sidney and 2005 at Akron, foxtail and proso millet were not successfully grown. Hail destroyed the crop in 2004 and soil crusting prevented successful es-

tablishment in 2005. As a result, there are two site-years of data for wheat after proso and foxtail millet and four site-years of data for wheat following triticale and dry pea.

Precipitation during the two winter wheat seasons varied from slightly above normal in 2004–2005 to well below average in 2005–2006 (Table 2). At Sidney, dry soil conditions at planting in 2005, combined with little precipitation after planting, resulted in the need to apply 13 mm of supplemental irrigation on 28 September in order to germinate wheat seed planted into foxtail or proso millet stubble. Supplemental irrigation was again applied at Sidney in early June of 2006 to partially compensate for a very hot and dry period in May and early June.

Soil Water and Water Use by Wheat

The differences in water content among the three water treatments at the time of summer fallow replacement crop planting (Table 1) were still apparent at the subsequent wheat seeding (Table 3), and also varied by previous crop treatment. Soil water at wheat seeding was always greater in the high water treatment than in the low water treatment. Apparently, the short-season summer crops used in this study did not need, or were unable to use, all the available soil water in the high water treatments. Consequently, this unused soil water was available for use by the subsequent winter wheat crop.

Plant available soil water at wheat seeding was not affected by previous crop in three of four site-years. However, at Sidney in 2005, plant available water in the surface 120 cm of soil at wheat seeding averaged 17.0 cm following early planted summer crops (triticale and dry pea) and 11.0 cm following late planted crops (foxtail and proso millets). Triticale was harvested 24 June and dry pea 20 July 2005, while foxtail was harvested 16 Aug. and proso millet 30 Aug. 2005. The earlier harvest dates of triticale and dry pea allowed greater opportunity to capture and store precipitation in the soil prior to winter

Table 3. Influence of previous summer crop and starting soil water level on plant available water in the surface 120 cm of soil at the time of seeding winter wheat at Akron, CO, and Sidney, NE, in 2004 and 2005.

Treatment	Akron, CO		Sidney, NE	
	2004	2005	2004	2005
	cm			
Crop				
Triticale	9.4	13.9	5.7	18.1
Dry pea	9.6	14.6	6.8	15.8
Foxtail millet	8.5	—	—	12.3
Proso millet	9.1	—	—	9.7
Soil water level				
Low	7.8	11.5	5.3	12.8
Medium	10.1	14.4	5.4	13.6
High	9.5	16.9	8.2	15.5
Contrasts	P > F			
Early vs. late†	0.242	—	—	<0.001
Triticale vs. dry pea	0.805	0.381	0.227	0.002
Foxtail vs. proso	0.508	—	—	<0.001
Low vs. high	0.133	0.042	0.014	<0.001

† Triticale and dry pea were planted in early April while foxtail and proso millets were planted in early June.

in 2005–2006, wheat yield was 1790 kg ha⁻¹ following early planted summer crops and 2240 kg ha⁻¹ following late planted crops. This difference in yield occurred despite wheat using 6.1 cm more water when it followed early planted summer crops (Table 4).

Plant available soil water at wheat seeding at Akron in 2004 averaged 9.5 cm following early planted crops and 8.8 cm following late planted crops (Table 3). At Sidney in 2005, available soil water at wheat seeding averaged 17.0 cm following early planted crops and 11.0 cm following late planted crops. The greater difference in starting soil water between early and late planted summer crops at Sidney compared with Akron may partially explain the difference in winter wheat response to the crop treatments between these two sites. At Sidney, winter wheat following the early planted summer crops germinated and began rapid growth about 2 wk earlier than winter wheat following the late planted summer crops. Supplemental irrigation was required to germinate wheat seed planted into foxtail and proso millet stubble. The earlier start of wheat growth following the early planted summer crops, combined with greater soil water availability and above normal autumn (September and October) precipitation at Sidney (Table 2), resulted in a visible growth advantage to wheat plants following triticale and pea that persisted throughout most of the season. However, hot and dry conditions in May and June resulted in greater terminal drought stress in wheat following triticale and dry pea than in wheat following foxtail or proso millet.

The effect of terminal drought can be seen by looking at the number of reproductive tillers (Table 6) and harvest index data (Table 7). Wheat following early planted summer crops at Sidney averaged 200 reproductive tillers m⁻¹ of row compared with 163 tillers m⁻¹ after late planted summer crops. However, an increased number of reproductive tillers did not translate into increased yield because of terminal drought stress. The

Table 6. Influence of previous summer crop and starting soil water level on the number of reproductive tillers in the subsequent winter wheat crop at Akron, CO, and Sidney, NE, in 2004–2005 and 2005–2006.

Treatment	Akron, CO		Sidney, NE	
	2004–2005	2005–2006	2004–2005	2005–2006
	no. m ⁻¹ of row			
Crop				
Triticale	201	187	247	214
Dry pea	172	179	255	186
Foxtail millet	154	–	–	164
Proso millet	183	–	–	161
Soil water level				
Low	155	201	241	165
Medium	181	172	246	184
High	196	177	266	194
Contrasts	<i>P</i> > <i>F</i>			
Early vs. late†	0.111	–	–	<0.001
Triticale vs. dry pea	0.061	0.612	0.638	0.014
Foxtail vs. proso	0.064	–	–	0.753
Low vs. high	0.004	0.231	0.207	0.004

† Triticale and dry pea were planted in early April while foxtail and proso millets were planted in early June.

Table 7. Influence of previous summer crop and starting soil water level on the harvest index of the subsequent winter wheat crop at Akron, CO, and Sidney, NE, in 2004–2005 and 2005–2006.

Treatment	Akron, CO		Sidney, NE	
	2004–2005	2005–2006	2004–2005	2005–2006
	g g ⁻¹			
Crop				
Triticale	0.102	0.294	0.205	0.150
Dry pea	0.149	0.317	0.233	0.174
Foxtail millet	0.074	–	–	0.227
Proso millet	0.110	–	–	0.258
Soil water level				
Low	0.074	0.258	0.188	0.196
Medium	0.117	0.296	0.216	0.232
High	0.136	0.362	0.253	0.179
Contrasts	<i>P</i> > <i>F</i>			
Early vs. late†	0.102	–	–	<0.001
Triticale vs. dry pea	0.097	0.338	0.282	0.412
Foxtail vs. proso	0.203	–	–	0.299
Low vs. high	0.015	0.002	0.050	0.507

† Triticale and dry pea were planted in early April while foxtail and proso millets were planted in early June.

harvest index for wheat following early planted summer crops averaged 0.162 compared with 0.243 following late planted summer crops. Angus and van Herwarden (2001) refer to this negative yield response, when vigorous vegetative growth is followed by a terminal drought, as *haying off*. At Akron, the smaller difference in starting soil water for wheat between the early and late planted crop treatments, combined with near-normal seasonal precipitation, both in terms of quantity and timing, resulted in no crop treatment differences.

Annualized Net Return

Annualized net return for the 2-yr system of summer fallow replacement crop and winter wheat was greatest in the high water treatment in three of the four site-years (Table 8). Only at Sidney in 2005–2006 were there no differences in annualized net return between water treatments. This may partially be explained by above average fall and early spring precipitation in 2004–2005, which restricted the range of beginning soil water levels

Table 8. Influence of previous summer crop and starting soil water level on the annualized net return (USD, U.S. dollars) of the summer crop and the subsequent winter wheat crop at Akron, CO, and Sidney, NE.

Treatment	Akron, CO		Sidney, NE	
	2004–2005	2005–2006	2004–2005	2005–2006
	USD ha ⁻¹			
Crop				
Triticale	22A†	157A	24A	176C
Dry pea	–133B	–169B	–149B	–159D
Foxtail millet	18A	–	–	239B
Proso millet	–6A	–	–	333A
Soil water level				
Low	–87c	–33b	–118c	140a
Medium	–19b	–15b	–70b	151a
High	31a	29a	0a	151a

† Means within a column and treatment category followed by the same letter and in the same case are not significantly different from one another at the 5% probability level.

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